cherenkov telescope array

The Future of γ-ray Particle Astrophysics

Presentation to P5
December 2, 2013

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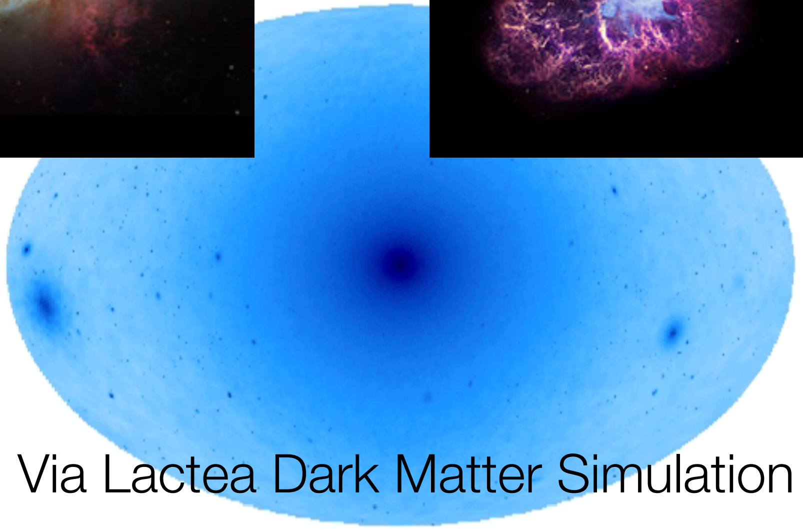
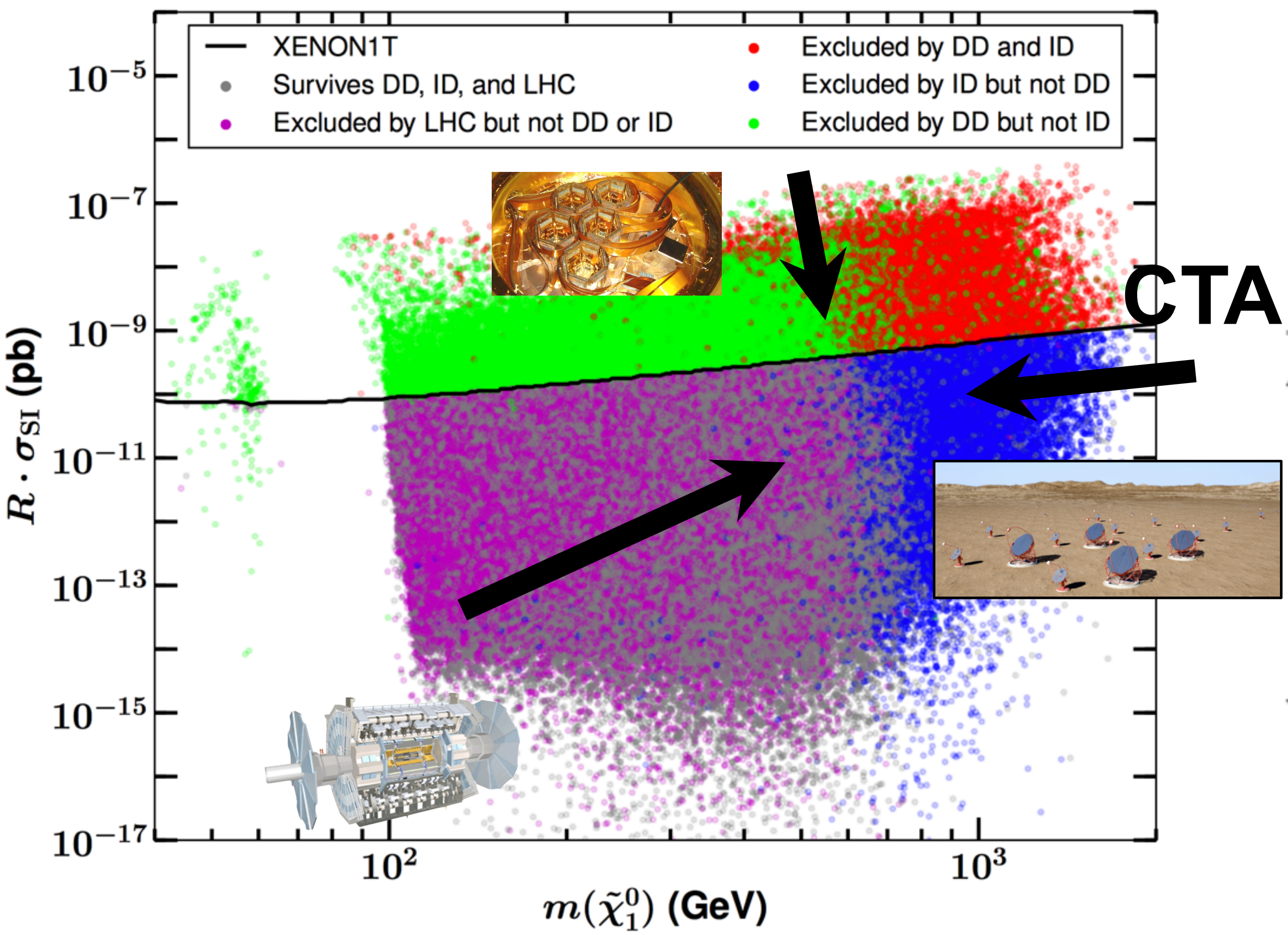
on behalf of CTA-US and the CTA Consortium
www.cta-observatory.org

CTA — A Worldwide Effort in VHE Particle Astrophysics

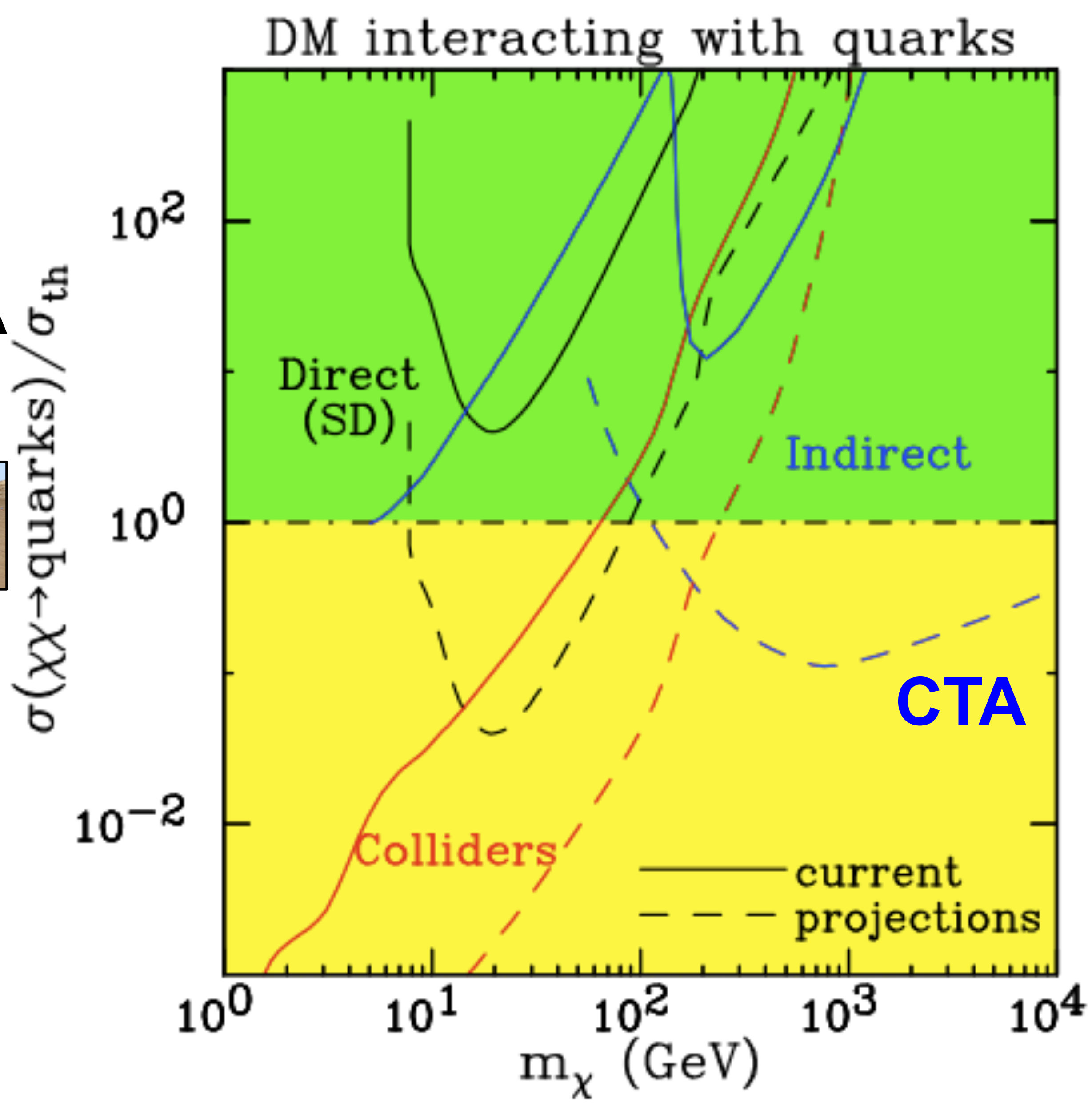

Via Lactea Dark Matter Simulation

- Great potential in fundamental physics and astrophysics revealed by the success of current instruments
- Worldwide community has come together around this single project
  - ✓ Previous reviews: PASAG, Astro2010, ESFRI, etc..
- CTA has been in development for >5 years
  - ✓ Imaging atmospheric Cherenkov technique, pioneered in U.S., is well understood
  - ✓ Detailed work on design and simulations
  - ✓ Established international collaboration
  - ✓ Prototype U.S. telescope under construction (MRI $3.8M NSF + $1.3M cost share)
  - ✓ >$2M local U.S. investment in R&D (LDRD, university funds, faculty startup)
- Propose critical enhancement to CTA baseline to fully achieve >10-fold advance in sensitivity
  - ✓ $79M (including project management & 30% contingency, 2013$)
  - ✓ Construction over five years, starting in 2017; NSF lead agency

Unique Dark Matter Results with CTA



Constraints:
$\Omega_{DM}h^2 > 0.1$, XENON100 (2011),
CMS+ATLAS (2012)

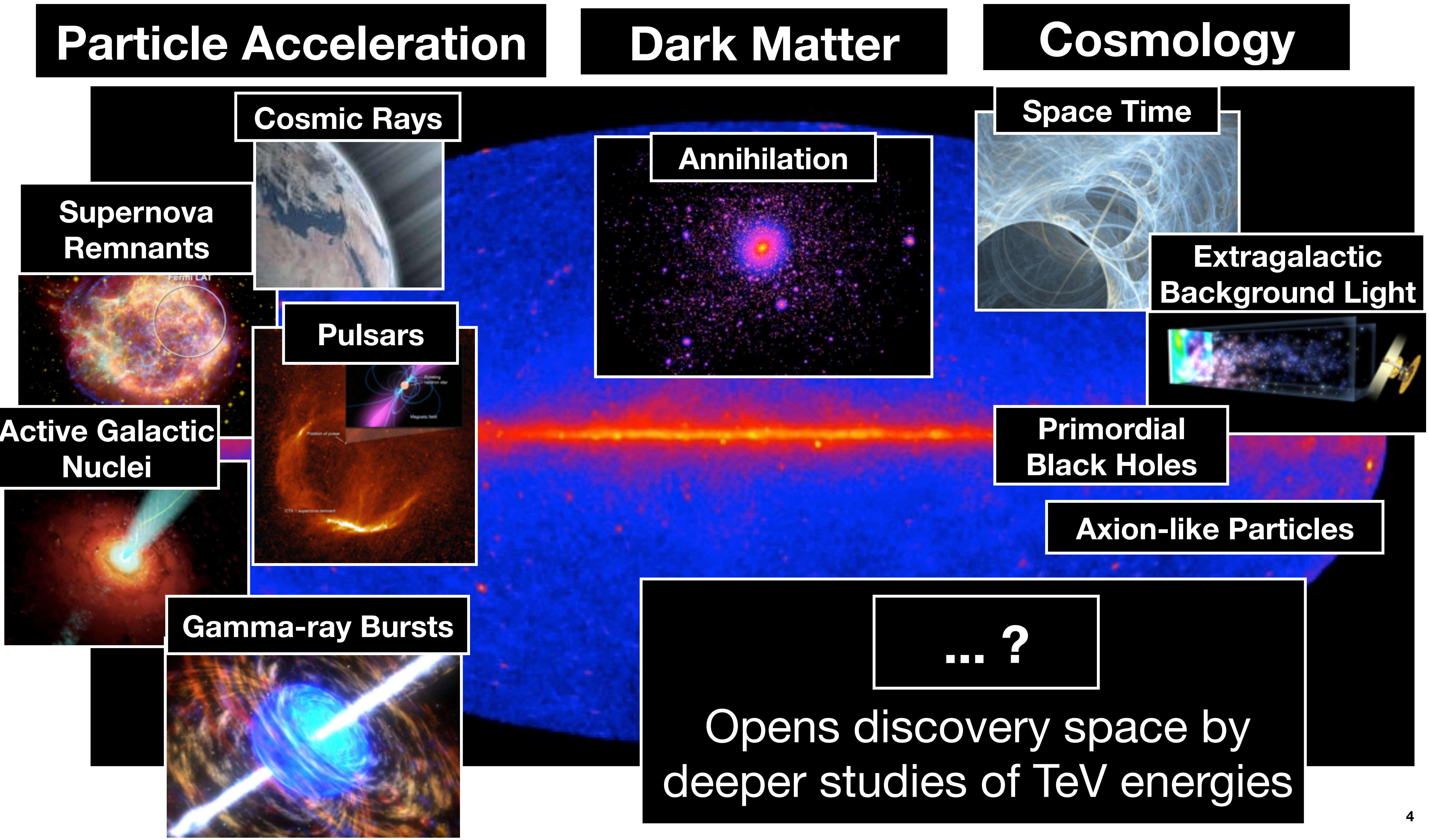


CTA results include U.S. contribution

M. Cahill-Rowley et al. – Snowmass white paper, arXiv:1305.6921

D. Bauer et al. – Snowmass complementarity report, arXiv:1305.1605

Broad Spectrum of Science



10 to 300 Times Improved Sensitivity to Lorentz Invariance Violation

Potential of GUT scale physics to reveal itself in LIV effects

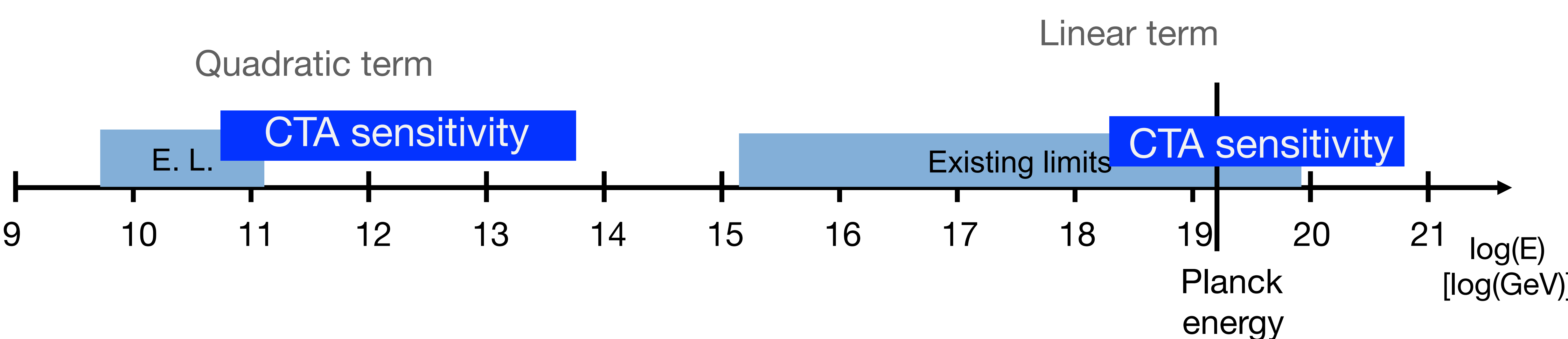
Variable gamma-ray sources (pulsars, AGN, and GRB) provide the most stringent tests of LIV effects in the photon dispersion relation

CTA will provide 10 to 300 times improved sensitivity on LIV tests
(arXiv:1305.0264)

$$c'(E) = c + \underbrace{a \cdot \frac{E}{E_{\mathrm{LIV}}}}_{\Delta t_1 = \frac{d}{c} \cdot \frac{E_{\mathrm{h}} - E_{\mathrm{l}}}{E_{\mathrm{LIV}}}} + \underbrace{b \cdot \left(\frac{E}{E_{\mathrm{LIV}}}\right)^2}_{\Delta t_2 = \frac{d}{c} \cdot \frac{3}{2} \cdot \frac{E_{\mathrm{h}}^2 - E_{\mathrm{l}}^2}{E_{\mathrm{LIV}}^2}}$$

Linear term Quadratic term

Current best limits from Fermi-LAT
(arXiv: 1305.3463)



Snowmass Conclusions about CTA

cherenkov telescope array

CF2 Report:

- ✓ "CTA, with a critical enhancement provided by the U.S., would provide a powerful new tool for searching for dark matter, covering **parameter space not accessible to other techniques** (direct searches, accelerator)."

CF4 Report:

- ✓ "The sensitivity of both direct searches and colliders is increasingly diminished at high masses, and this is where indirect detection probes play an important complementary role — in the case of couplings to quarks and leptons, CTA arrays are able **to cover the relevant parameter region in the mass range around 1 TeV**."

CF6 Report:

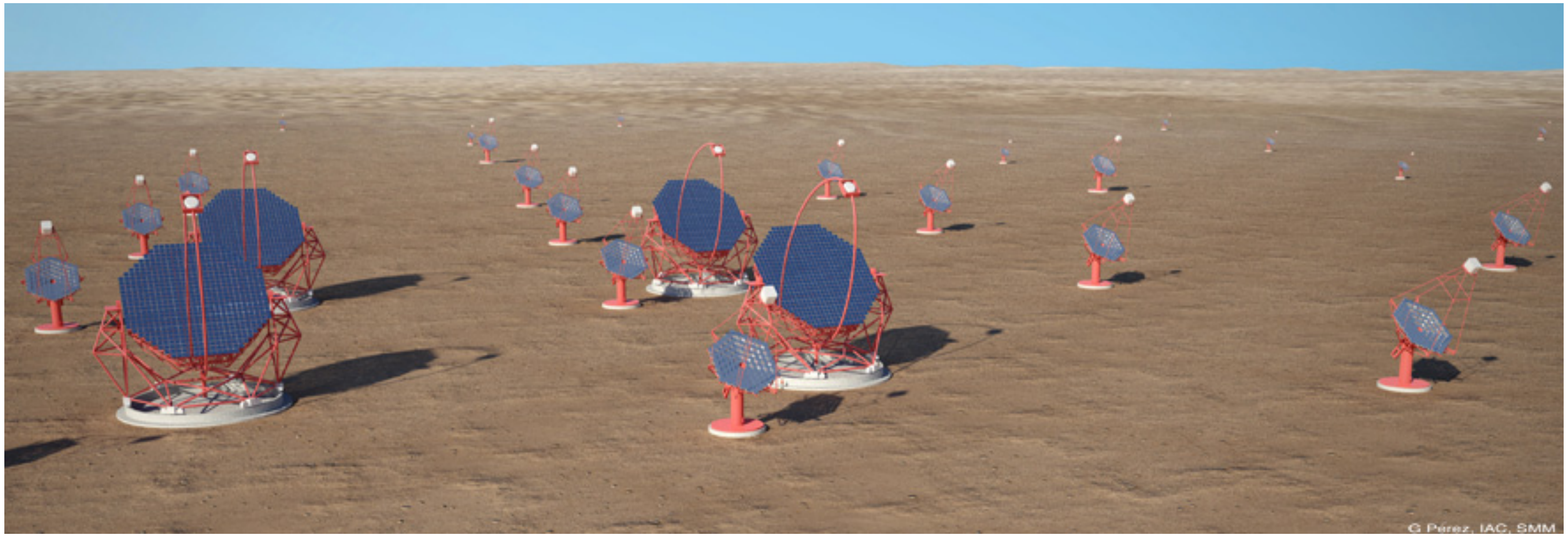
- ✓ "CTA will usher in the era of precision VHE astrophysics and in conjunction with current instruments (Fermi and HAWC) will provide a view of the high-energy universe that will lead to an understanding of the astrophysical processes at work in these extreme objects and enable us to **probe the laws of physics** at energies, couplings, and mass scales that are **beyond the reach of traditional high-energy physics experiments**."

CF Summary Report:

- ✓ "[CTA], with the critical U.S. enhancement, will provide a powerful new tool for searching for dark matter, covering parameter space not accessible to other techniques. [It] will provide **new information to help identify the particle nature of the dark matter** and determine the halo profile."

- ✓ **"U.S. involvement in CTA is critical."**

The CTA Concept — Baseline + U.S.

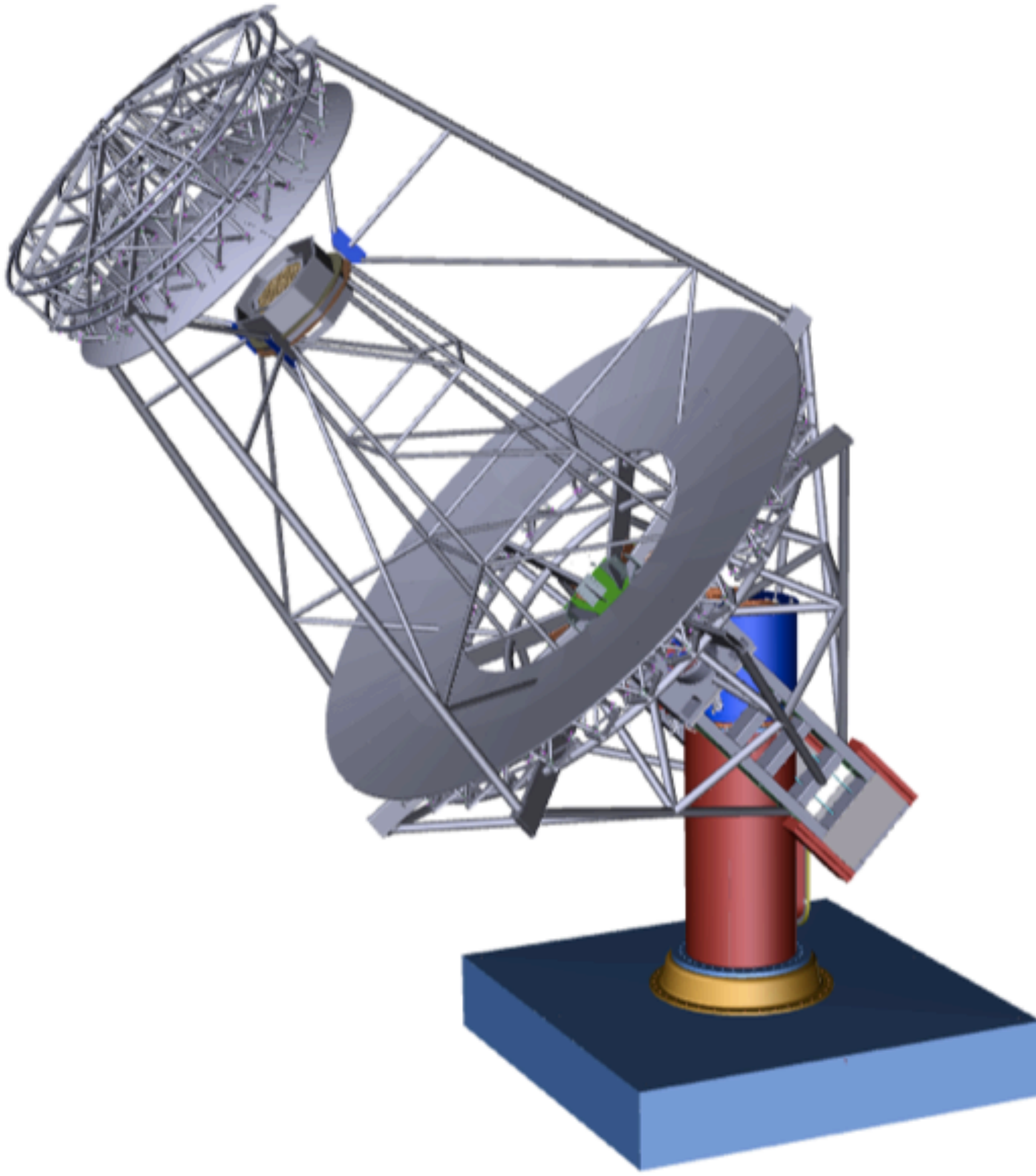


- Arrays in northern and southern hemispheres for full sky coverage
- Southern array:
  - 4 large (23 m) telescopes in the center (LSTs) — threshold of 30 GeV
  - 25 medium (9-12 m) telescopes (MSTs)
  - Small (~4 m) telescopes (SSTs) covering >3 km^2 — expand collection area >10 TeV
- **U.S. proposal is to add 24 MSTs with a higher-performance, two-mirror design to southern array — achieve 1 km^2**

  More than order of magnitude sensitivity improvement in 100 GeV–10 TeV range

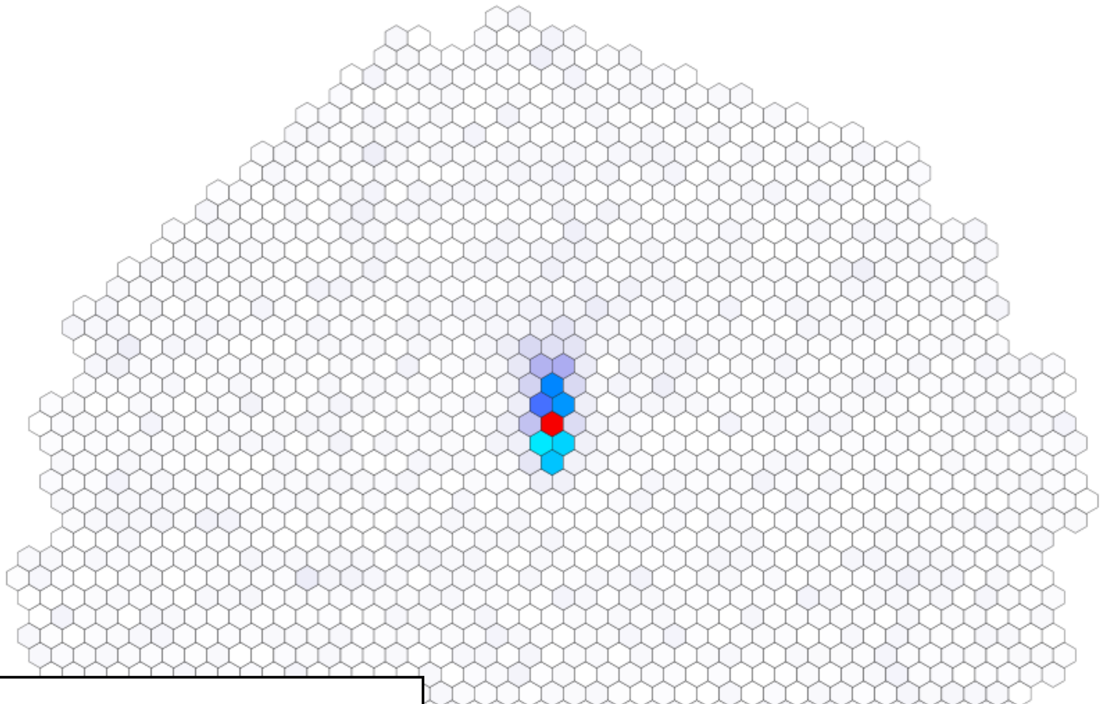
Two-Mirror Atmospheric Cherenkov Telescope: The Schwarzschild-Couder Telescope (SCT)

- Innovative U.S. design key to boosting CTA performance
- Corrects aberrations providing higher resolution, wider field
- Small plate scale enables SiPM camera
- Deep analog memory waveform samplers to minimize dead-time and allow flexible triggering
- High level of integration into ASICs allows dramatic cost savings (<$80 per channel) and high reliability (11,328 channels)
- Overall cost comparable to baseline single-mirror medium-sized telescope
- Adopted now by European groups also for small-sized telescopes

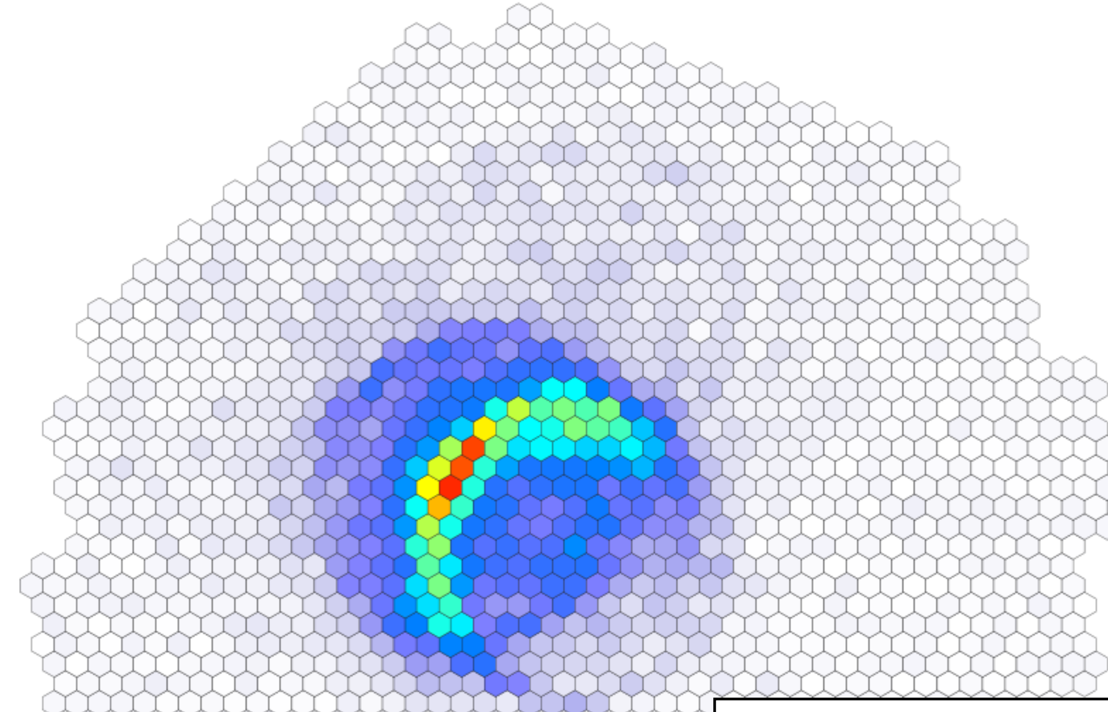


Uses the same positioner and foundation as baseline single-mirror MST

Adding Two-mirror Telescopes: More Showers, Measured Better

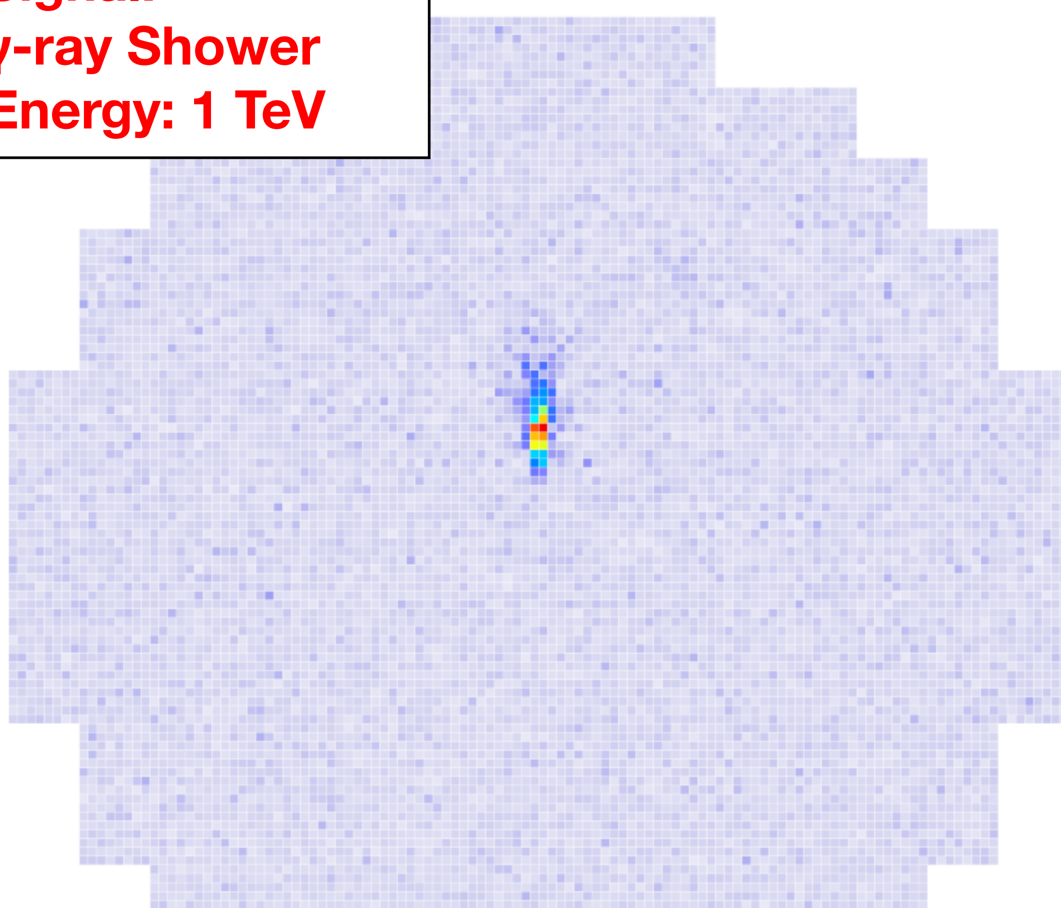


Baseline Single-Mirror
Telescope
Images
8° field of view
0.18° pixels
1,570 channels

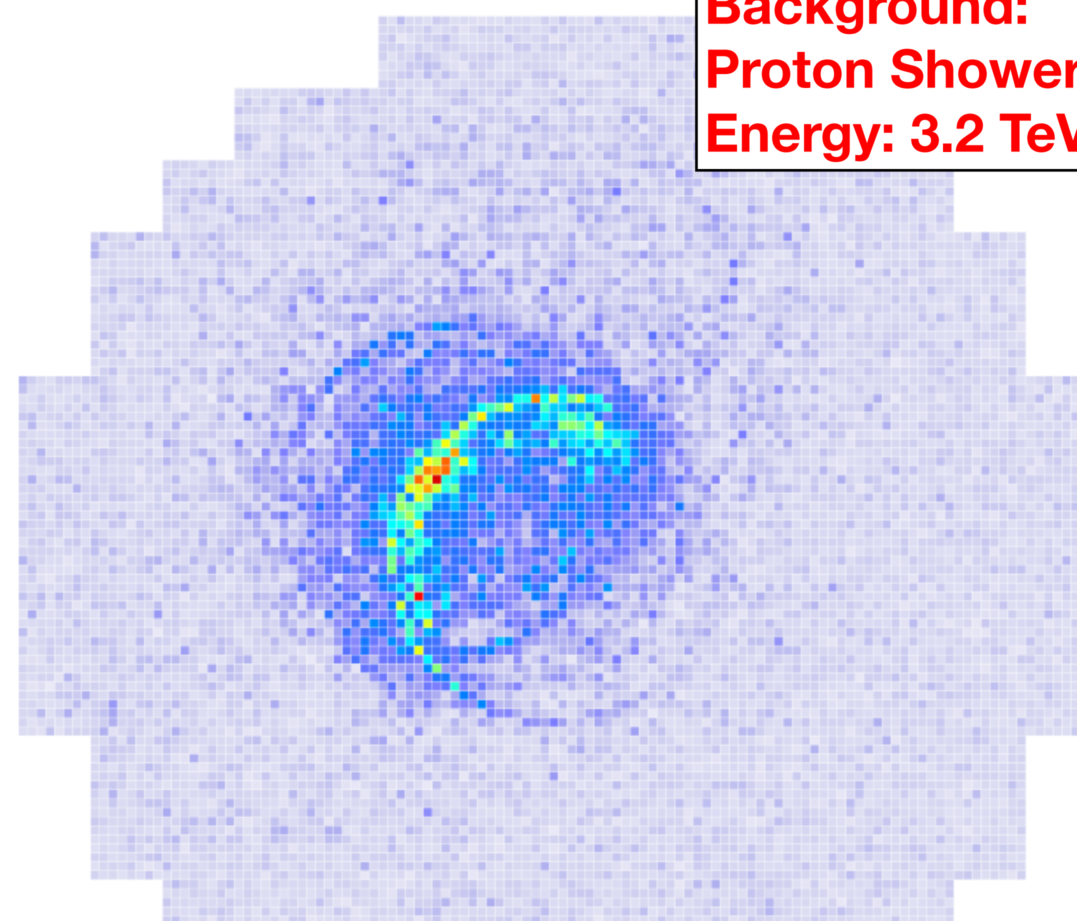


Signal:
γ-ray Shower
Energy: 1 TeV

Background:
Proton Shower
Energy: 3.2 TeV



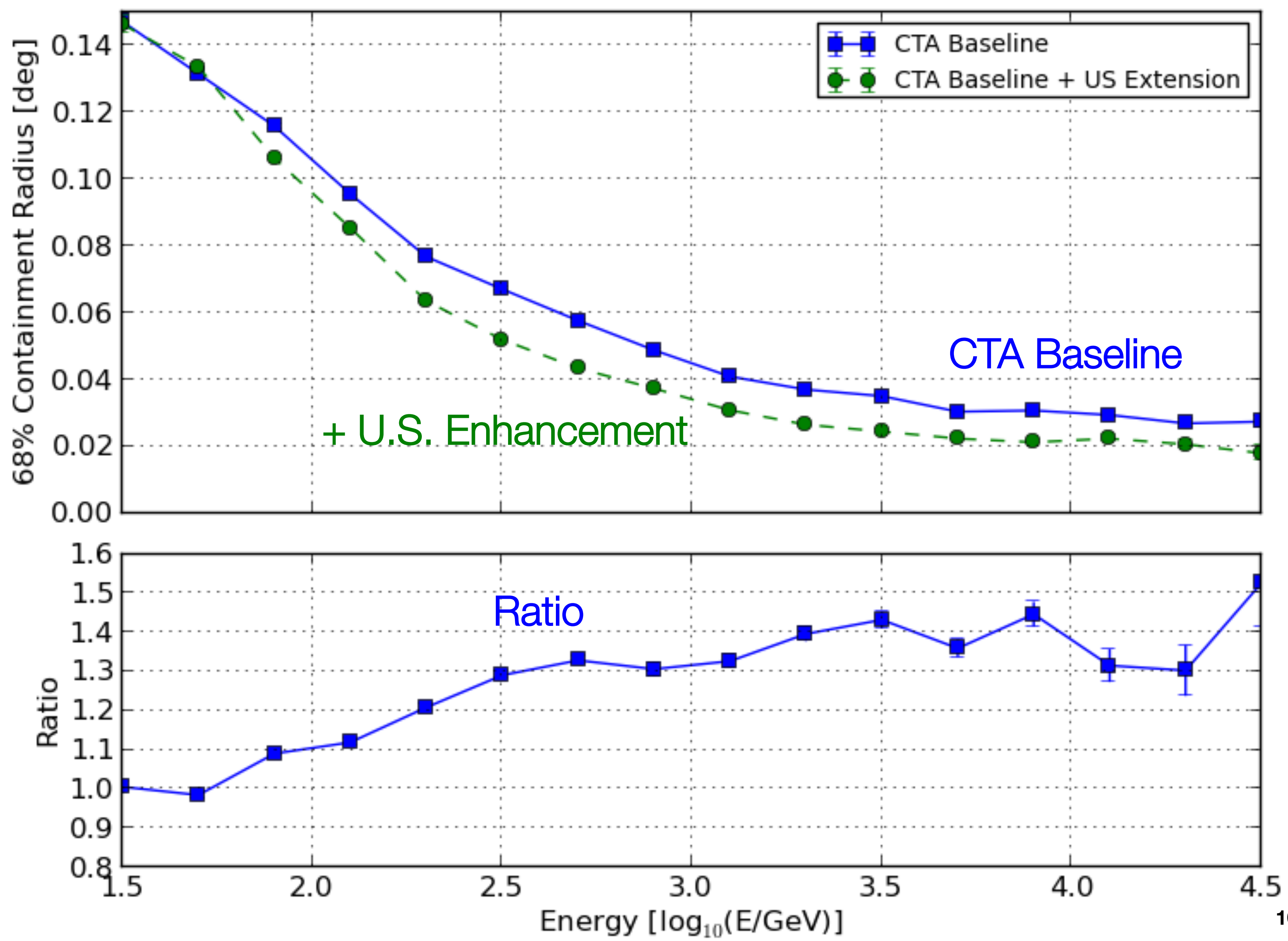
U.S. Design Two-Mirror
Telescope
Images
8° field of view
0.067° pixels
11,328 channels



Impact of U.S. Participation

- **Improved angular resolution and wide field of view — both critical for dark matter studies**

Angular Resolution
68% containment radius



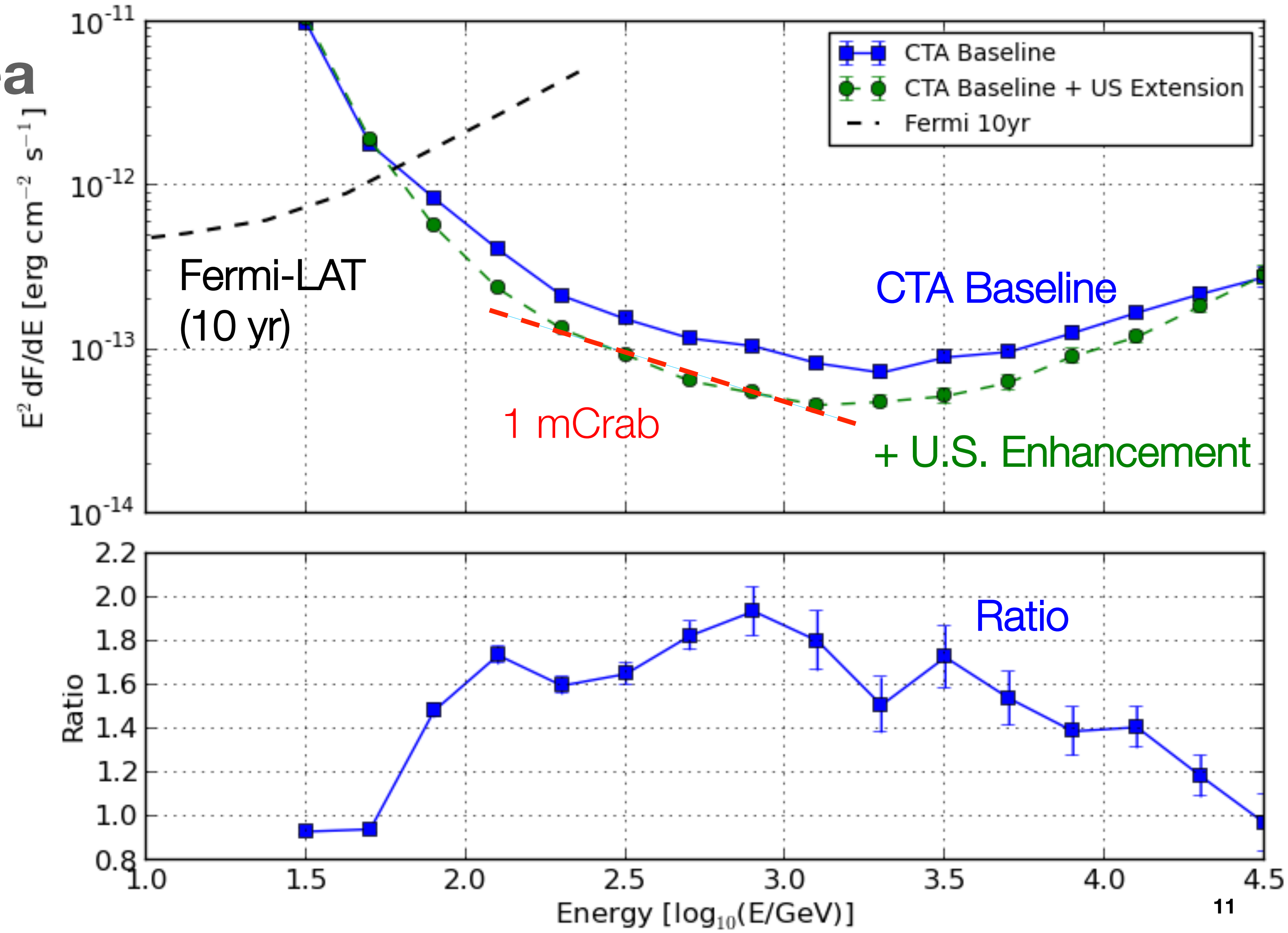
30–40% better angular resolution above 300 GeV

Impact of U.S. Participation

- Improved angular resolution and wide field of view — both critical for dark matter studies
- **Doubles the collection area of the array (from 25 to 49 telescopes) and nearly doubles the sensitivity**

Equivalent to a factor of 3–4 reduction in observing time: Makes possible results impossible with the baseline array.

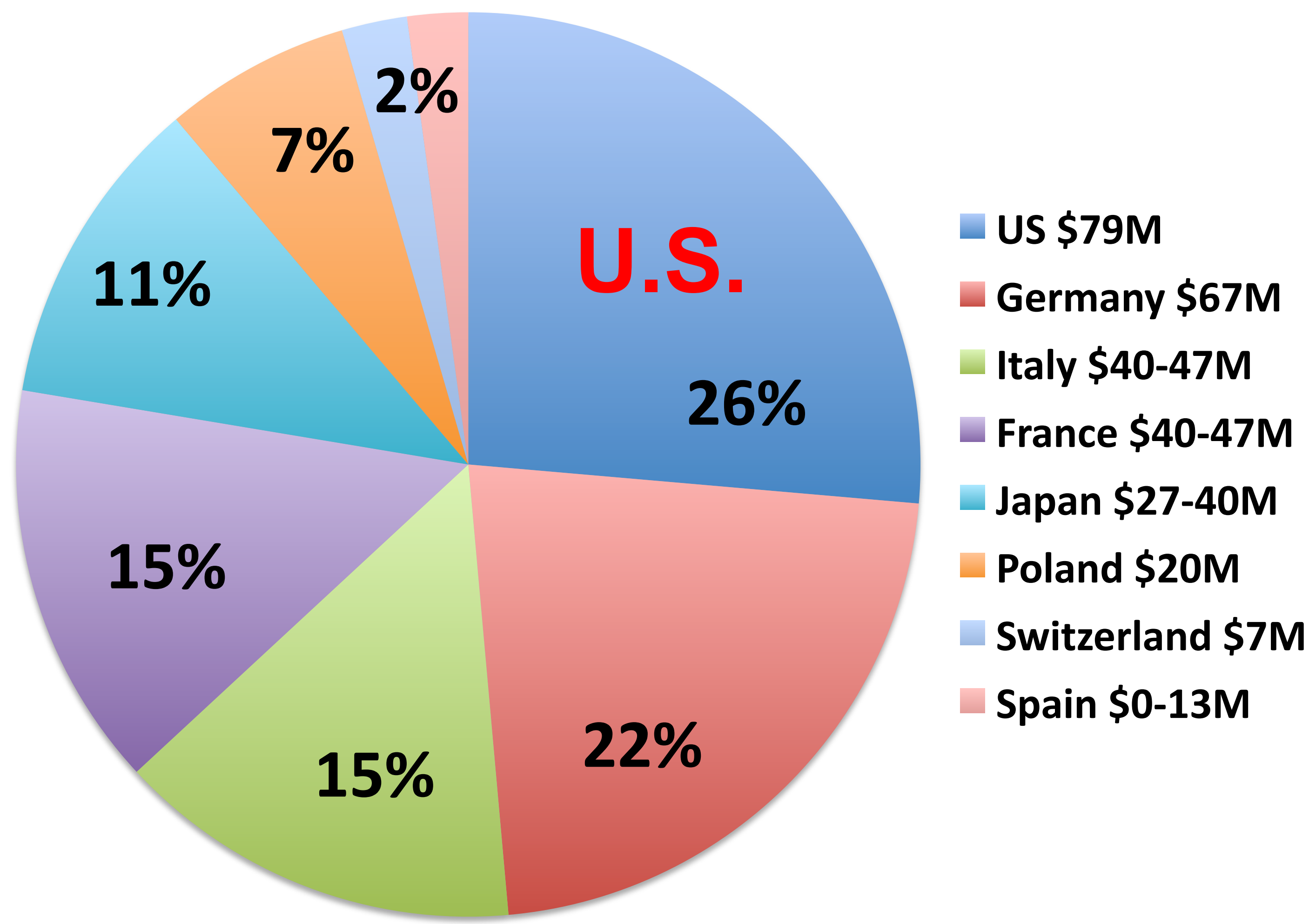
Point Source Sensitivity
50 hour observation



Impact of U.S. Participation

- Improved angular resolution and wide field of view — both critical for dark matter studies
- Doubles the collection area of the array (from 25 to 49 telescopes) and nearly doubles the sensitivity
- **Largest single financial contribution to CTA construction**

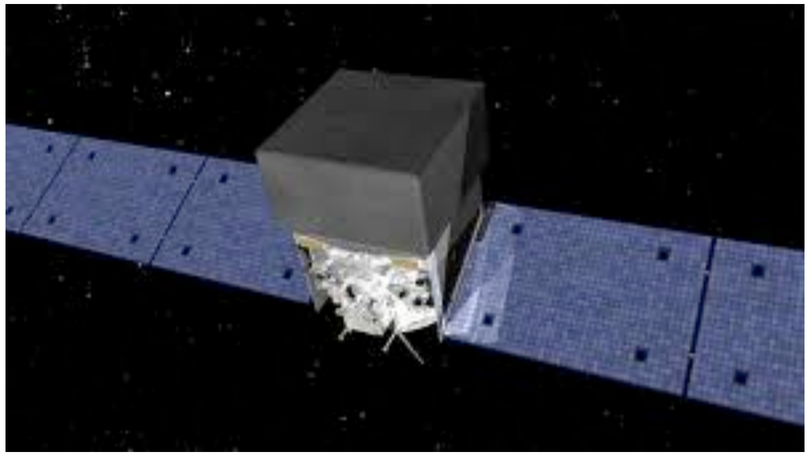
Estimated Construction Contributions: $300M



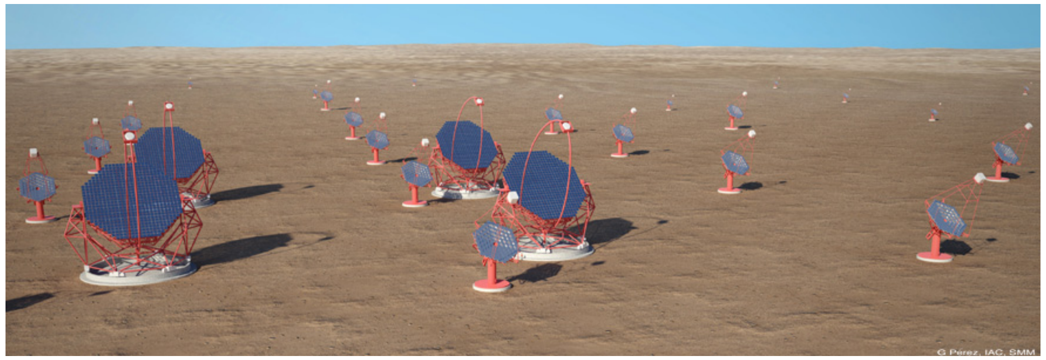
Leadership role and influence setting the science program

Impact of U.S. Participation

- Improved angular resolution and wide field of view — both critical for dark matter studies
- Doubles the collection area of the array (from 25 to 49 telescopes) and nearly doubles the sensitivity
- Largest single financial contribution to CTA construction
- **U.S. will be major contributor to the CTA performance and major participant in the CTA science**



Fermi-LAT: Instrument team has the biggest impact

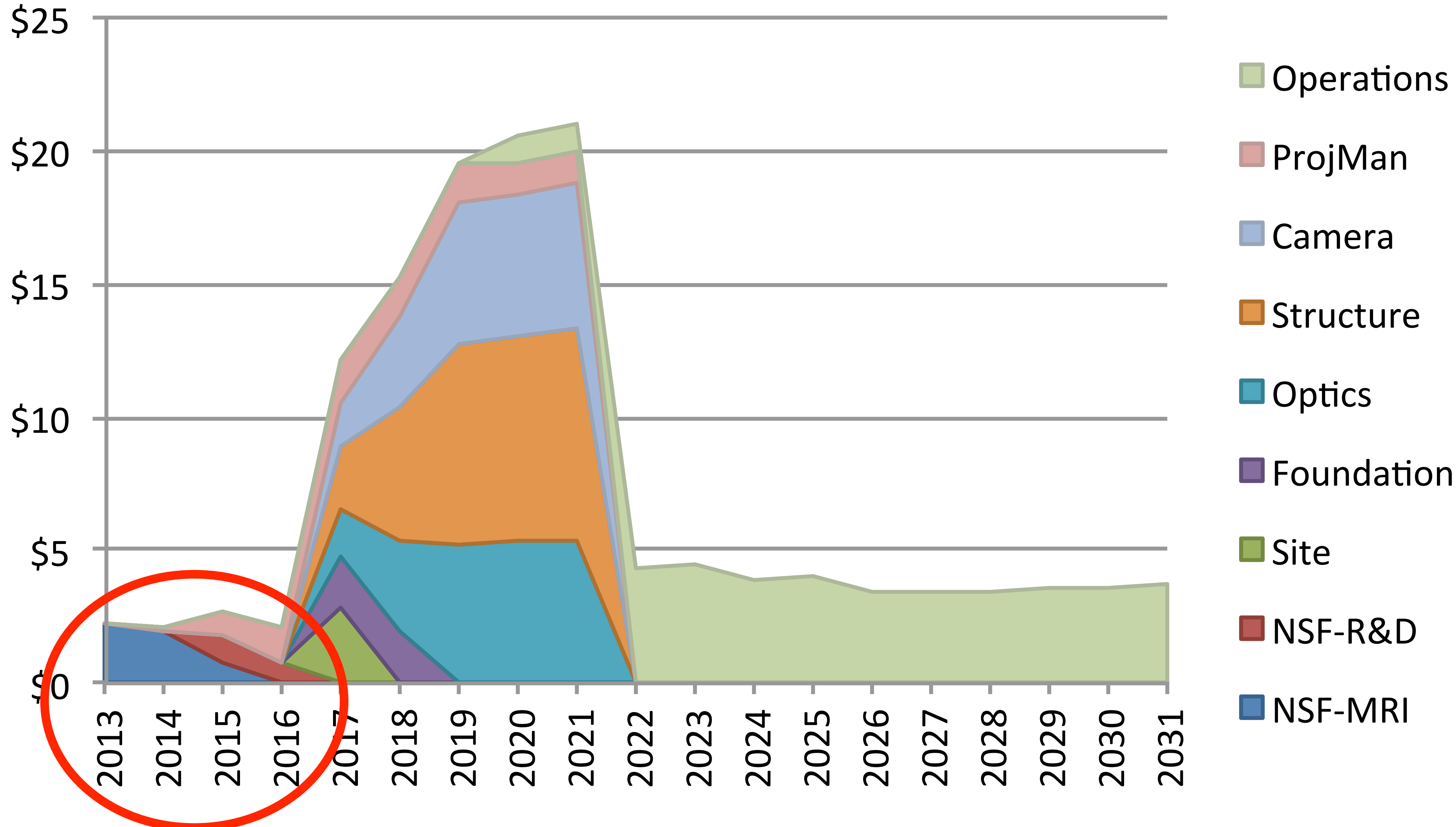


CTA: Key Science Projects will have observing time and data proprietary to the CTA Consortium

"We consider the USA contribution essential to boost the capabilities of CTA..."
— Werner Hofmann, CTA Spokesperson (full letter uploaded to P5 portal)

Cost and FTE Profile: R&D Phase

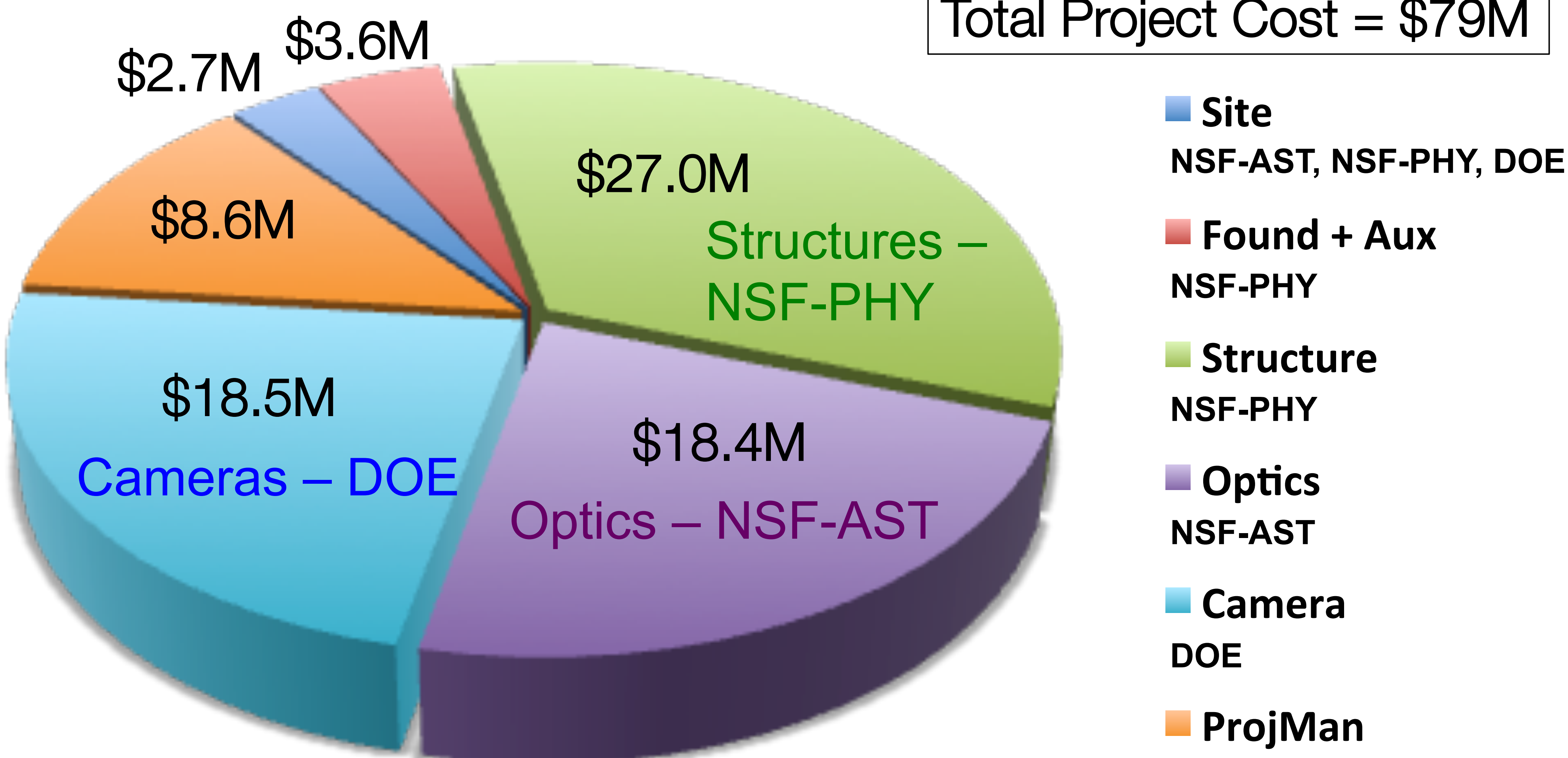
- Scale is $M per year, in actual year $
- Funded: NSF MRI proposal for (partial) prototype $3.8M NSF + $1.3M cost share
- Submitted to NSF-PHY: $1.7M over 2 years for systems engineering, R&D to improve telescope design & cost, integration with CTA-wide planning
- 102 people, 33 FTE (current): SLAC, ANL & 19 university groups



Construction Costs

- Costs based on prototype experience, additional R&D, preliminary design review
- Includes 30% contingency
- Includes $8.6M for project management (bottom-up estimate, with contingency)
- Costs in 2013$

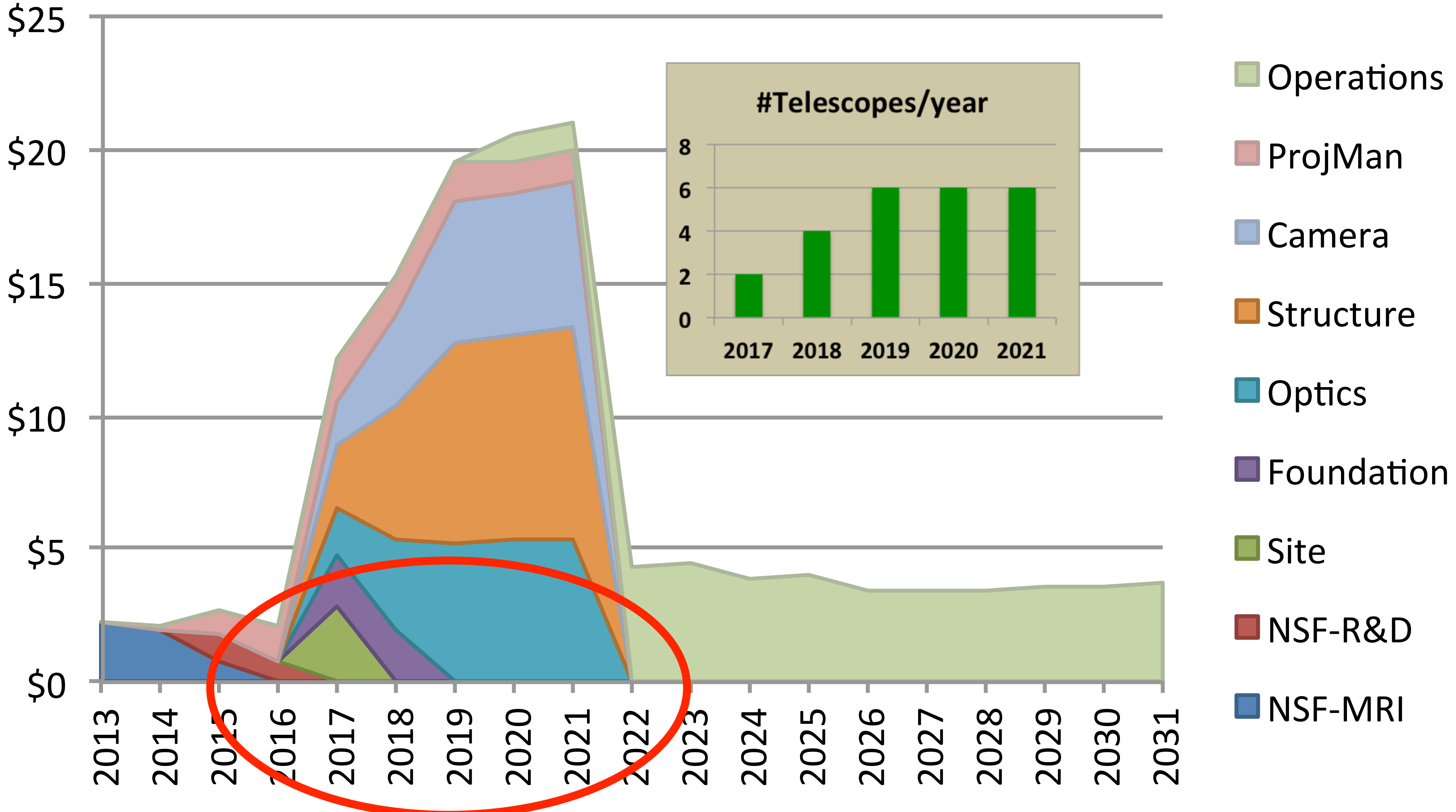
Total Project Cost = $79M



DOE: $22.4M NSF-AST: $22.2M NSF-PHY: $34.3M

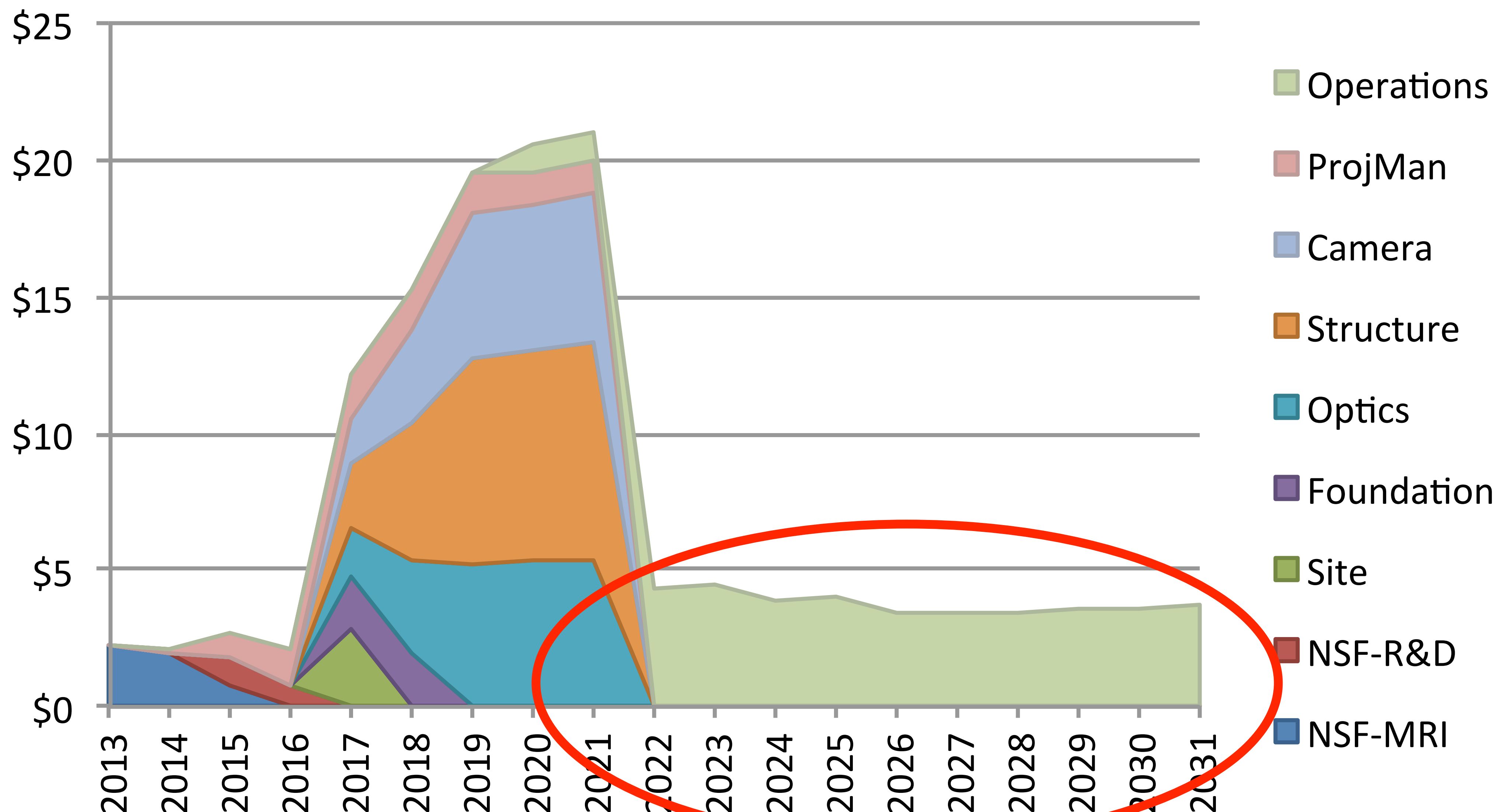
Cost and FTE Profile: Construction Phase

- Scale is $M per year, in actual year $, assuming 2% annual inflation
- Cost based on prototype experience, additional R&D, CTA PTDR
- Includes 30% contingency and $8.6M (2013$) for project management
- Assumes operations start at a small level during last 2 years of construction
- 150 people, 75 FTE (estimate)

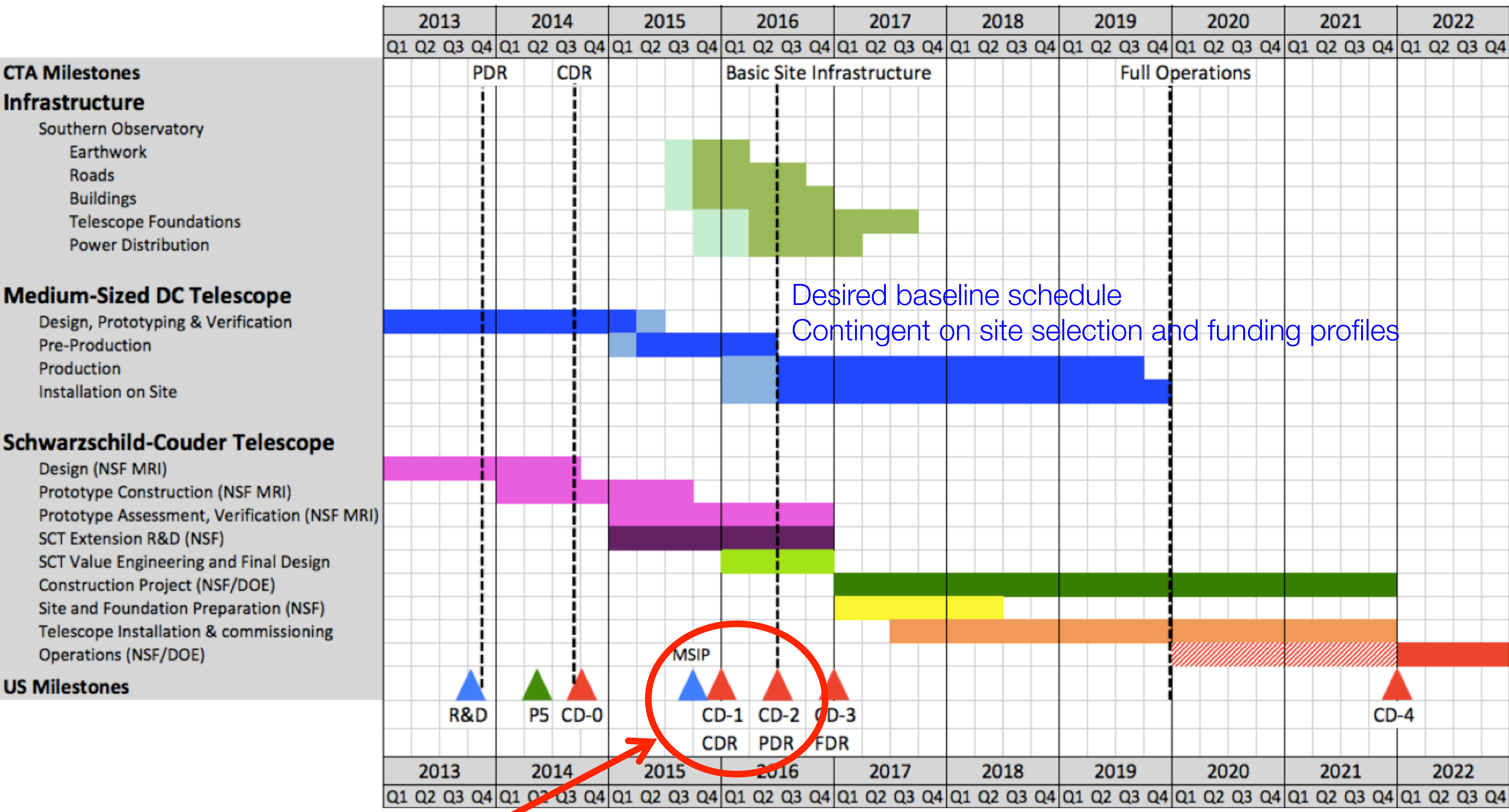


Cost and FTE Profile: Operations Phase

- Scale is $M per year, in actual year $, assuming 2% annual inflation
- Annual cost based on top-down estimate of 7% of capital investment, decreasing somewhat with time and experience
- Assumes operations start at a small level during last 2 years of construction
- Anticipate little/no role for NSF-AST (similar to VERITAS)
- 150 people, 75 FTE (estimate); U.S. user community of >300



CTA Project Timeline



Decision points on final scope of U.S. participation

The Analogy to the LHC

- Widespread appreciation worldwide of the importance of the science goals
- Scale of the project argues for a single international facility
- International partners committed to providing the necessary basic infrastructure
- Science too important for the U.S. not to participate
- U.S. brings extensive experience, new ideas, and important resources to the project
- U.S. can be a leading participant in the science results

CTA — The Future of γ-ray Particle Astrophysics

- Builds on decades of U.S. leadership, investment and success
- Exciting science with CTA recognized by Snowmass, Astro2010 and PASAG
  - ✓ One of the pillars of a coherent dark matter program
- U.S. participation essential to CTA realizing its full potential and achieving its science goals
- Strong international participation leverages U.S. contribution; a single worldwide effort
- CTA will be the premier VHE particle astrophysics experiment for decades to come

Backup

Reviews of CTA and Basis of Cost Estimate

CTA has been in development since 2006, both in Europe and in US.

Previous reviews:

- 2009: HEPAP PASAG – endorsed science, recommended significant funding in scenarios B and C.
- 2010: NRC Astro2010 – ranked project (one of only 3 on ground), approximate US funding ~ $100M.
- 2013: Preliminary Technical Design Report (PTDR) of entire CTA project, including SCT array.

  CTA preliminary design review of SCT work package

PTDR Cost Estimate for US Contribution:

- Bottom-up estimate for prototype using WBS/PBS to Level 4.
- Detailed Cost Book covering construction, integration and verification.
- Reviewed by external Science & Technology Advisory Committee (STAC).
- Will be refined as we complete the prototype telescope construction.

U.S. Leadership in γ-ray Astrophysics

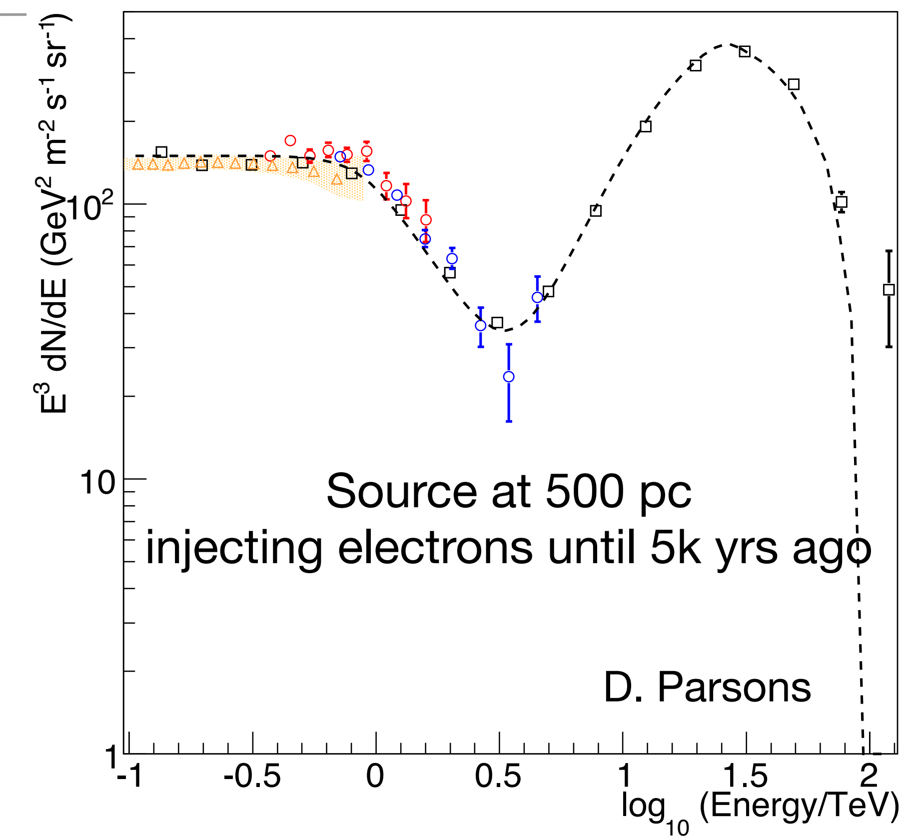
- Developed the IACT technique
  - ✓ Successfully applied in Whipple 10-m telescope to first discoveries
  - ✓ Provides by far the best angular and energy resolution of any TeV technique
  - ✓ VERITAS sensitivity unsurpassed >100 GeV
- EGRET and Fermi-LAT in the high energy regime
- Developed the water Cherenkov technique
  - ✓ Milagro the first extensive air shower array to convincingly see sources
  - ✓ HAWC the premier wide-aperture VHE instrument world wide
- Continued leadership in CTA
  - ✓ Builds on Fermi-LAT and VERITAS success
  - ✓ Two-mirror IACT design conceived in the U.S. – now adopted by European groups for CTA small-sized telescopes (less demanding)
  - ✓ TARGET camera ASIC conceived in the U.S. with HEP heritage – critical to low cost per channel and affordable, high-resolution camera (likewise adopted in England)
  - ✓ U.S. contribution to CTA construction would be among the largest of any nation
  - ✓ U.S. impact on CTA performance would be *the largest* of any nation

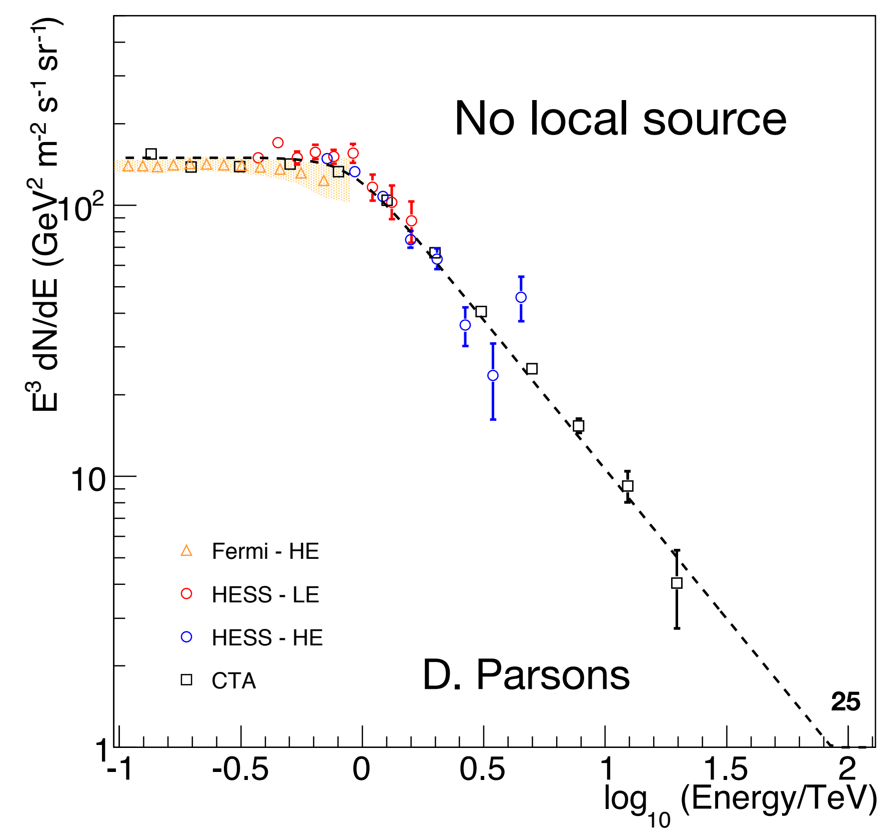
U.S. Effort Builds on VERITAS Success

- One of only a few executed projects from the 2000 decadal survey
- Built on schedule and on budget after delays related to site and funding were resolved
- Unsurpassed sensitivity in >100 GeV energy band
- Most reliable instrument operating in >100 GeV energy band
- Several of the most important VHE γ-ray discoveries from the last ~5 years
  - ✓ Gamma-ray emission from the starburst galaxy M82
  - ✓ Evidence for proton acceleration in Tycho's supernova remnant
  - ✓ The most distant VHE gamma-ray source, PKS 1424+240
  - ✓ Best dark matter limit for a dwarf galaxy, Segue I
  - ✓ Crab Pulsar emission >100 GeV
- Upgrade completed on schedule and on budget
- Design of experiment yields good understanding of systematic effects as we move into the regime of very deep observations

The electron + positron spectrum

- CTA will measure total electron + positron spectrum well beyond AMS, up to 30-100 TeV
- CTA can also measure positron fraction above 1 TeV using Moon shadow
  - ✓ Requires good TeV sensitivity, good discrimination between hadronic and electromagnetic showers, and ability to observe in moonlight conditions
  - ✓ All are provided by SCT design of U.S. telescopes
- CTA will also measure anisotropy by comparing different sky directions
- arXiv:1305.0022





CTA Project Timeline